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The software support for an identification of stochastically loaded parts of mechanically structures

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Abstract

The paper deals with one of possible ways of an identification of stochastically loaded mechanically structures. The purpose of this approach is to find an algorithm of a forecasting control of their working in real working conditions. It deals with a proposal of an application of vector time series moving average models (VARMA). Their parameters are possible to determine using the nonlinear modification of the least squares method. The paper contains a theoretical principle of problems solved and a description of a real testing methodise. There is added a brief interpretation of results of used software verification.

Keywords: mechanically structure, working conditions, stochastic load, identification, modelling, vector autoregressive model VARMA, virtual model of crane jib, software support - ArmaGet, Excel, ARMASA Package

1. Introduction

It is well known that working of majority of machines is significantly influenced by different kinds of stochastic loads. There is possible to respect the tendency a limitation of energetically and material consumption to oversize their dimensions. But it is necessary to look for some more ingenious methods to deal with this problem`s. Some of them are the ways to control (influence) the working of a mechanical system in respect to their proposed behaviour. But it needs to follow of the system behaviour in the real time and to make some necessary controlling interventions.

2. The vector autoregressive moving average models and the possibility to using them in stochastically loaded dynamic systems identification

There is necessary to identify such a system at first. It means to get its statistically adequate mathematical model. There is possible by using this model and by developing sufficient fast and correct machine control system and suitable software to forecast behaviour of system in the near future. We can get in such a way the possibility of making some controlling corrections before the system reaches an unstable region.

2.1. Vector autoregressive moving average models (VARMA)

It was found the as a suitable solution for a stochastically loaded mechanical structure identification can be used the autoregressive moving average models ARMA or their vector modification VARMA (Vector Autoregressive Moving Average) models [1], [4] and [9].

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A stochastically loaded part of structure and its behaviour during time can be described by using of scalar autoregressive moving average model (ARMA). Its identification (stochastically adequate model) but gives just an information about its own behaviour without a relationship to the whole structure during acting of different working regimes.

We have found as one of possible ways the use of vector autoregressive moving average models VARMA to improve accuracy of stochastically loaded mechanical structures identification. These models are suitable for stochastically loaded mechanical structures identification which outputs are reflections on stochastically loads in more number of points – vector time series (fig.1).

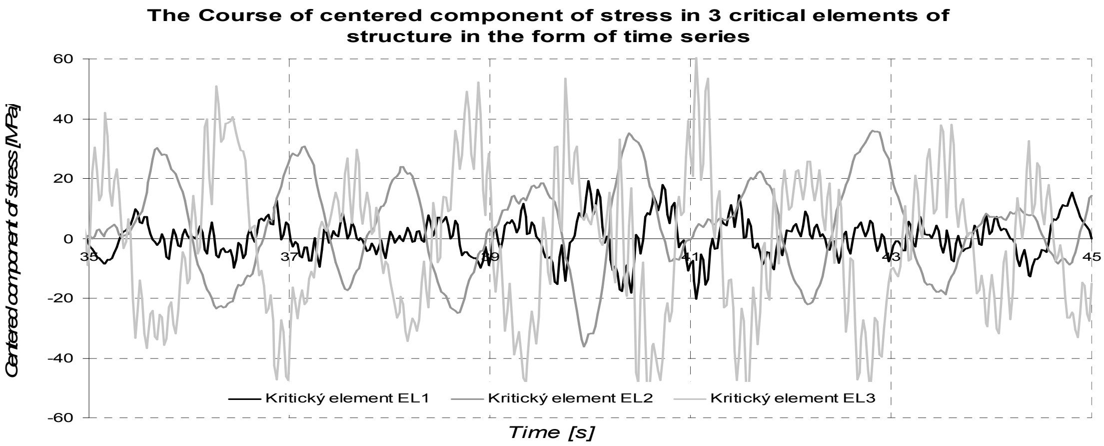

Fig. 1. A Vector Time Series.

A searched vector model VARMA (m,n) can be expressed as a matrix equation in form

$$\mathbf{x_t} - \mathbf{A_1}.\mathbf{x_{t-1}} - \mathbf{A_2}.\mathbf{x_{t-2}} - \ldots - \mathbf{A_m}.\mathbf{x_{t-m}} = \boldsymbol{\varepsilon}_\mathbf{t} - \mathbf{B_1}.\boldsymbol{\varepsilon}_\mathbf{t-1} - \mathbf{B_2}.\boldsymbol{\varepsilon}_\mathbf{t-2} - \ldots - \mathbf{B_n}.\boldsymbol{\varepsilon}_\mathbf{t-n} \tag{1}$$

or in written out form

$$\begin{bmatrix} x_{1t} \\ x_{2t} \\ \ldots \\ x_{kt} \end{bmatrix} - \begin{bmatrix} a_{111} & a_{121} & \ldots & a_{1k1} \\ a_{211} & a_{221} & \ldots & a_{2k1} \\ \ldots & & & \\ a_{k11} & a_{k21} & \ldots & a_{kk1} \end{bmatrix} . \begin{bmatrix} x_{1t-1} \\ x_{2t-1} \\ \ldots \\ x_{kt-1} \end{bmatrix} - \begin{bmatrix} a_{112} & a_{122} & \ldots & a_{1k2} \\ a_{212} & a_{222} & \ldots & a_{2k2} \\ \ldots & & & \\ a_{k12} & a_{k22} & \ldots & a_{kk2} \end{bmatrix} . \begin{bmatrix} x_{1t-2} \\ x_{2t-2} \\ \ldots \\ x_{kt-2} \end{bmatrix} -$$

$$- \ldots - \begin{bmatrix} a_{11m} & a_{12m} & \ldots & a_{1km} \\ a_{21m} & a_{22m} & \ldots & a_{2km} \\ \ldots & & & \\ a_{k1m} & a_{k2m} & \ldots & a_{kkm} \end{bmatrix} . \begin{bmatrix} x_{1t-m} \\ x_{2t-m} \\ \ldots \\ x_{kt-m} \end{bmatrix} = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \ldots \\ \varepsilon_{kt} \end{bmatrix} - \begin{bmatrix} b_{111} & 0 & \ldots & 0 \\ 0 & b_{221} & \ldots & 0 \\ \ldots & & & \\ 0 & 0 & \ldots & b_{kk1} \end{bmatrix} . \begin{bmatrix} \varepsilon_{1t-1} \\ \varepsilon_{2t-1} \\ \ldots \\ \varepsilon_{kt-1} \end{bmatrix} - \tag{2}$$

$$- \begin{bmatrix} b_{112} & b_{122} & \ldots & b_{1k2} \\ b_{212} & b_{222} & \ldots & b_{2k2} \\ \ldots & & & \\ b_{k12} & b_{k22} & \ldots & b_{kk2} \end{bmatrix} . \begin{bmatrix} \varepsilon_{1t-2} \\ \varepsilon_{2t-2} \\ \ldots \\ \varepsilon_{kt-2} \end{bmatrix} - \ldots - \begin{bmatrix} b_{11n} & 0 & \ldots & 0 \\ 0 & b_{22n} & \ldots & 0 \\ \ldots & & & \\ 0 & 0 & \ldots & b_{kkn} \end{bmatrix} . \begin{bmatrix} \varepsilon_{1t-n} \\ \varepsilon_{2t-n} \\ \ldots \\ \varepsilon_{kt-n} \end{bmatrix} .$$

This can be transformed in the system of k linearly independent equations. The symbol of “k” means number of points of the structure in which the output on dynamic loads are recorded.

The left hand side of matrix equation (1) expresses the dependence of vector time series values on former values of the series and the right hand side shows the relationship of stochastically random deviations.

2.2. The possibilities and advantages of VARMA models

The application of VARMA models as an alternative to the systems of differentials equations for stochastically loaded structures identification is suitable from different point of view too. If we can express the system of differential equations in a simplified form [7] as

$$\mathbf{M}.\ddot{\mathbf{x}}+\mathbf{K}.\dot{\mathbf{x}}+\mathbf{C}.\mathbf{x}=\mathbf{F}(\mathbf{t}) \tag{3}$$

respectively in matrix formulation

$$\begin{bmatrix} m_1 & 0 & \dots & 0 \\ 0 & m_2 & \dots & 0 \\ \dots & & & \\ 0 & 0 & \dots & m_n \end{bmatrix} . \begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \dots \\ \ddot{x}_n \end{bmatrix} + \begin{bmatrix} k_{11} & k_{12} & \dots & k_{1n} \\ k_{21} & k_{22} & \dots & k_{n2} \\ \dots & & & \\ k_{n1} & k_{n2} & \dots & k_{nn} \end{bmatrix} . \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dots \\ \dot{x}_n \end{bmatrix} +$$

$$+ \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{n2} \\ \dots & & & \\ c_{n1} & c_{n2} & \dots & c_{nn} \end{bmatrix} . \begin{bmatrix} x_1 \\ x_2 \\ \dots \\ x_n \end{bmatrix} = \begin{bmatrix} f_1(t) \\ f_2(t) \\ \dots \\ f_n(t) \end{bmatrix} . \tag{4}$$

We can judge the matrix of damping $\mathbf{K}$ and the matrix of stiffness $\mathbf{C}$ as a mathematical expression of the relationship among the individual parts of structure. The matrix coefficients as $\mathbf{a}_1, \mathbf{a}_2, ..., \mathbf{a}_\mathbf{m}$ of a vector model VARMA are the mathematical expressions of individual parts interaction.

The advantages of VARMA models:

- they can show the physically base of problem studied (this means that they to obtain the natural frequencies and natural modes of vibrations) [3],
- they can describe a wanted accuracy of real system [5] and [6],
- the mathematical apparatus of these methods is relative simple so that it can be used for “real time control” [1] and [7].

3. The software support of a proposed method of identification

The scalar models of a simple description of dynamic system can not express statistically adequate description of complex systems. For this reason there was developed an effective software system which enables to create the statistically models of dynamic stochastic system by using VARMA models. The accuracy and the reliability of the developed methods and algorithms were verified by use of commercial software packages (Microsoft Excel and MATLAB).

3.1. The procedure of the creating of software for an identification support

The creation of a software support which is able to identify some stochastic loaded parts of structures is just the firs step for applying of the forecasting control of mechanical systems.

The final form of an identification software was created in such a way that it enables the use of an identification library and to realise the own identification of system parameters. The result of a proposed application of this methodology is ArmaGet software (fig.2) which is fully compatible with Microsoft Windows systems.

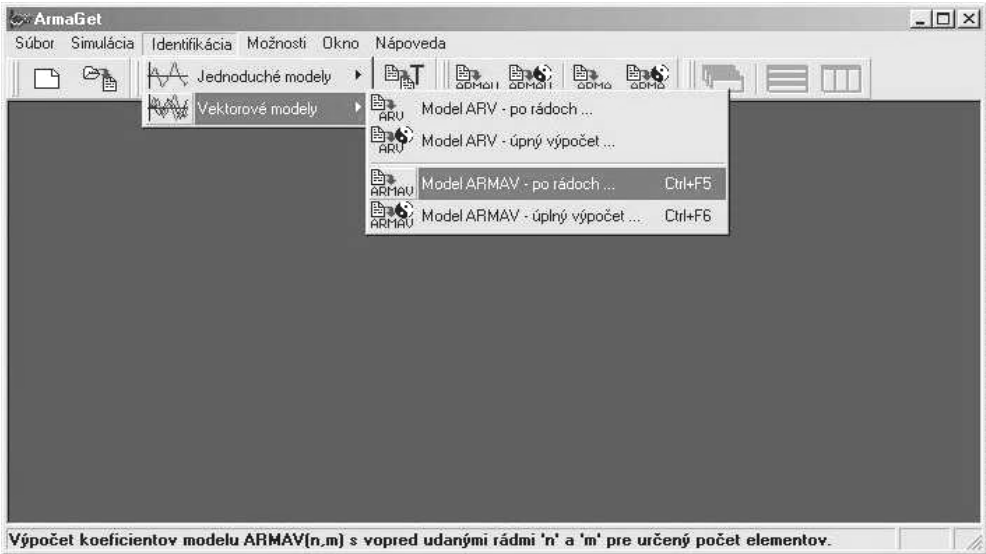

Fig. 2. Main window of application ArmaGet.

This developed software is able to create an adequate mathematical model for describing a matrix model of a tested stochastic loaded mechanical system.

3.2. A real application of the proposed procedure of identification

There was developed a FEM (Finite Element Method) model of a crane jib (fig.3) and in MATLAB-environment was realised simulation of its loading. The acting loads were described as a stochastic excitation.

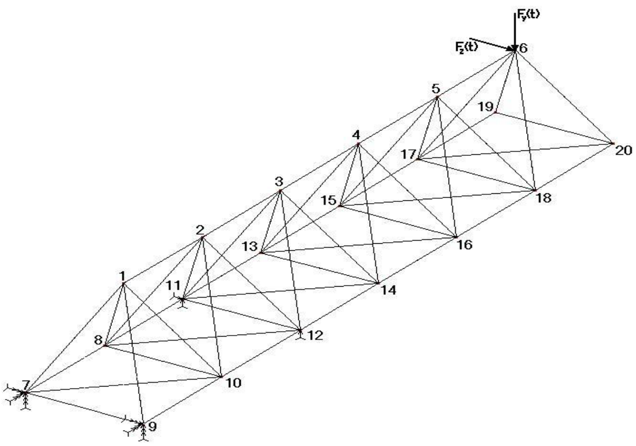

Fig. 3. Testing model of crane jib.

There were used as an application of a numeric Crank-Nicolson method [8] of direct integration the deformation of all nodes of model (20 nodes). The time intervals were selected as $\Delta t_{vz} = 0.01$ s. Resulting deformational outputs were organized in corresponding vector time series.

There was selected in a testing example a vector time series of deflection in “z” axe direction. The determination of vector time series in direction of “z” axe is introduced in fig.4 and results of identification are introduced in fig.5 (an optimal order of model is VARMA (6,5)).

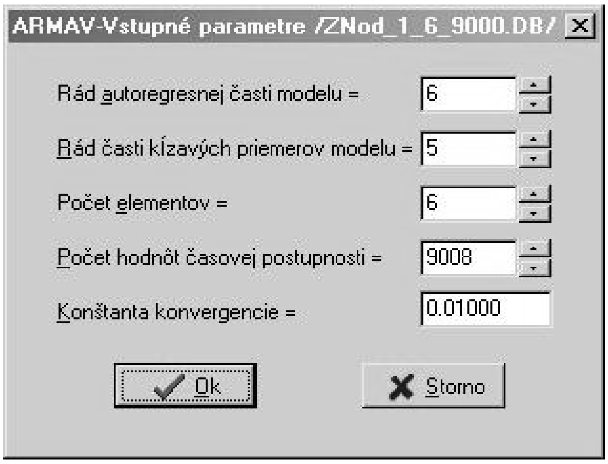

Fig. 4. Settings of input parameters.

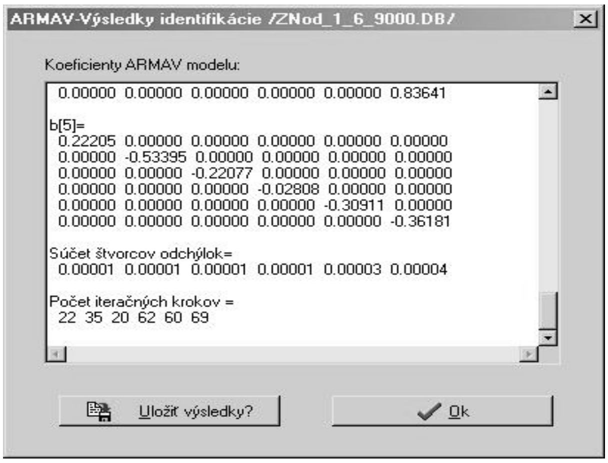

Fig. 5. Results of a crane jib upper boom identification – an optimal model VARMA (6,5).

The verification of developed software ArmaGet was realised by two different ways. At first it was the simulation of time series with determined parameters and their “back way” identification. This option is available by menu item *Simulation→ Model ARMAV*. The second way was a comparison with results of computing module Solver from MS Excel.

There are showed in tab.1 the results of an application of identification software ArmaGet and their comparison with results obtained using standard Excel surroundings (computing module Solver).

	VARMA(6,5)		**VARMA(8,7)**		**VARMA(10,9)**	
	ArmaGet	***Excel***	***ArmaGet***	***Excel***	***ArmaGet***	***Excel***
Node 1	$7,9591.10^{-6}$	$7,9606.10^{-6}$	$7,9251.10^{-6}$	$7,8991.10^{-6}$	$7,8985.10^{-6}$	$7,8398.10^{-6}$
Node 2	$1,0659.10^{-5}$	$1,1381.10^{-5}$	$1,0493.10^{-5}$	$1,1243.10^{-5}$	$1,0365.10^{-5}$	$1,1953.10^{-5}$
Node 3	$1,1204.10^{-5}$	$1,2789.10^{-5}$	$1,0689.10^{-5}$	$1,1868.10^{-5}$	$1,0424.10^{-5}$	$1,1307.10^{-5}$
Node 4	$1,4823.10^{-5}$	$2,4128.10^{-5}$	$1,4327.10^{-5}$	$2,1467.10^{-5}$	$1,4028.10^{-5}$	$2,0833.10^{-5}$
Node 5	$2,5955.10^{-5}$	$4,3874.10^{-5}$	$2,3396.10^{-5}$	$4,2690.10^{-5}$	$2,2255.10^{-5}$	$3,5906.10^{-5}$
Node 6	$4,1240.10^{-5}$	$8,4167.10^{-5}$	$3,8608.10^{-5}$	$6,4402.10^{-5}$	$3,7822.10^{-5}$	$6,2980.10^{-5}$

Tab. 1. The verification of the identification results (ArmaGet and Excel).

In the near future accuracy of the developed software support will be verified with confrontation of the accessible software ARMASA Packet made by Dr. P.M.T. Broersen [2].

4. Conclusion

It was shown that by using of a suitable mathematical apparatus can forecast the future behaviour of a mechanical structure. The vector time series (Vector Autoregressive Moving Average Models – VARMA) were chosen as a suitable mathematical apparatus and the suitability of this choice were proven by use of computer simulation of stochastically excited mechanical systems.

Acknowledgements

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